Revolutionizing Formal School Learning with Adaptive Training

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ABSTRACT

U.S. Marine Corps (USMC) formal schools are challenged to prepare Marines for increasingly complex and varied roles without a commensurate increase in instructor time or course duration. One promising technology-supported approach to maximizing learning efficiency is adaptive training, whose premise is to customize instruction to individual needs by measuring performance, then targeting individual deficiencies with tailored remediation (e.g., Landsberg, Mercado, Van Buskirk, Lineberry, and Steinhauser, 2012). The authors hypothesize that adaptive training tools can modernize formal school learning for the Marines in multiple ways. First, they enable self-paced learning of basic concepts so instructor-led time can be devoted to advanced topics and application. Second, they improve the remediation process by offering individualized support for knowledge gaps and misconceptions rather than a one-size-fits-all instructional approach. Finally, they increase instructor visibility on student performance.

The efficacy of the adaptive training paradigm was tested with entry-level Marines using the Adaptive Perceptual And Cognitive Training System (APACTS). Land navigation training was selected as the domain for this testing, and content was generated for ten classroom-based learning objectives. An experiment was conducted in which Marines were randomly assigned to the adaptive training or control group. Both groups received a 23-item pre-test, intervention, and 23-item post-test. The adaptive training group intervention consisted of targeted remediation on the learning objectives not mastered on the pre-test, while individuals in the control group received standard land navigation slides used by a preeminent Marine Corps school. Results indicate that the adaptive training group experienced a learning gain from pre- to post-test of 42.5% in contrast to the control group learning gain of 16.5%. This constitutes an effect size (Cohen's d) of 0.69 over the control condition. These results lend support to the incorporation of adaptive training into USMC formal schools for increasing the effectiveness and efficiency of training and education.

ABOUT THE AUTHORS

Amanda J. H. Bond is a Research Scientist and Principal Investigator at Soar Technology, leading and contributing to various technical efforts leveraging her background in Human Factors Engineering. With over 15 years spent in government research and commercial programs, Ms. Bond's expertise includes the design and development of numerous training and decision-support systems (both prototype and fielded), task and training needs analyses, and experimental and training efficacy evaluation. Ms. Bond has her M.S. in Modeling and Simulation (Human Performance) from the University of Central Florida, a B.S. in Psychology (Experimental) from Florida State University, and currently pursuing her Ph.D. in Modeling and Simulation (Human Performance) at the University of Central Florida.

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INTRODUCTION

Marine Corps Vision & Strategy 2025 (US Marine Corps Training and Education Command, 2008) discusses the need to "improve the ability of small unit leaders across the Marine Air-Ground Task Force (MAGTF) to improve their intuitive ability to assess, decide, and act while operating in a more decentralized manner (p.9)." In support of this desire, the United States Marine Corps (USMC) convened the Small Unit Decision Making (SUDM) workshop in 2011 (Small Unit Decision Making, 2011). The goal of the resulting SUDM initiative was to accelerate the acquisition of expertise at the small unit level by systematically emphasizing cognitive readiness and employing research-supported instructional techniques to better facilitate its development.

More recently, the Commanding General of Marine Corps Training and Education Command (TECOM), Major General Mullen, provided guidance heralding the need to move the USMC training paradigm from an industrial age model of lecture, rote memorization, and fact regurgitation to a learning environment focused on how to think, decide, and act (TECOM Memorandum, 2018). He calls for an information age model of active learner engagement, student-directed study, and training content linked to prescribed objectives to support Marines' cognitive readiness for the operational challenges likely to be faced on the modern battlefield. In his guidance, Major General Mullen also noted that many additional training requirements have been added to the Marine's overall curriculum, without necessarily increasing the training footprint (TECOM Memorandum, 2018). However, the number of instructors and the allotted training blocks have not been increased commensurately. The burden on instructors includes a shortage of time to address training requirements, ascertain and diagnose the performance of students, and remediate instructional needs of individual Marines. Furthermore, while the information age model means students share responsibility for their learning, this puts the onus on the individual Marine to self-study, self-assess, and self-remediate without the benefit of support from information age instructional tools and structures.

To move toward an information age model of learning while maintaining a focus on cognitive readiness across the force, instructional capabilities are required that can engage students, optimize instructor time, and tailor instruction to ensure the prescribed learning objectives are achieved by every individual. The purpose of this paper is to investigate the application of adaptive training as a key component of the solution.

Adaptive Training Systems

One-on-one human tutoring has been seen as the gold standard in teaching methodologies at least since Bloom's (1984) study showed a 2 sigma learning effect with one-on-one tutoring over traditional classroom instruction. Further research has indicated that the effectiveness of one-on-one tutoring stems from the tutor's ability to diagnose mistakes and to provide feedback, scaffolding, and remediation to target amendment of specific misconceptions (Van Lehn,

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2011). Unfortunately, one-on-one tutoring is costly, has a high manpower requirement, and is time consuming. These limitations make it infeasible for use in a military setting. To bridge this gap, researchers and software developers have looked towards Adaptive Training Systems (ATS) to fulfill the needs of improving training efficacy with technologies that can play the role of a human tutor. Adaptive Training Systems are instructional systems that adapt to the needs of a learner in real-time or after a training event (Landsberg, Van Buskirk, Astwood, Mercado, & Aakre, 2011).

Adaptive Training Techniques. Several adaptive training techniques are discussed in the Adaptive Training literature (Mödritscher, Garcia-Barrios, & Gutl, 2004; Park & Lee, 2003; Landsberg, Astwood, Van Buskirk, Townsend, Steinhauser, & Mercado, 2012). These techniques include Macro, Micro, Aptitude Treatment Interaction, and Two-step adaptations. Macro adaptation uses previous performance (a test or assessment usually) to guide adaptations, typically in the form of instructional content that targets the areas where performance was weak. Micro adaptation occurs during training and uses on-task performance to drive adaptations of feedback, scenario difficulty, and so forth. Aptitude Treatment Interaction involves adapting the instructional techniques or content based on a learner's aptitudes or abilities. Lastly, the Two-step approach combines the Micro and the Aptitude Treatment Interaction approaches so that the initial training approach is based on aptitudes and abilities and then the training adapts based on on-task performance during training.

Effectiveness of Adaptive Training Systems. Research has shown that ATS improve learning in many contexts (Park & Lee, 2003; Landsberg, Astwood, Van Buskirk, Townsend, & Steinhauser, 2012; Dzikovska, Steinhauser, Farrow, Moore & Campbell, 2014). Dzikovska and colleagues (2014), for example, developed an adaptive training system to teach Basic Electronics and Electricity that used the Micro adaptive approach to provide targeted feedback to learners as they learned about electrical concepts. Participants showed an average learning gain of 61% when working with the adaptive system and a 1.72 sigma (using Cohen's *d*) effect over a non-training control condition. This gain and effect was similar to a one-on-one human tutoring condition that showed learning gain averages of 72% and an effect size of 1.77 sigma compared to the non-training control condition. In another example, Landsberg and colleagues (2012) created an adaptive training system to teach Angle on the Bow estimation to naval periscope operators. Their adaptive system used the Micro adaptive approach to adapt both scenario difficulty and feedback as the participant worked through scenarios. Participants in their study showed an average learning gain of 32% with just one hour of training in the system.

Adaptive Perceptual and Cognitive Training System (APACTS)

Based on the success of previous research to accelerate learning and the need to push training into an information-aged approach, we developed an ATS for the USMC—APACTS. APACTS is a lightweight, web-based adaptive training system that supports macro-adaptation via the xAPI framework. APACTS tests a trainee's proficiency upfront and then tailors the remediation/curricular content to the needs of the learner using an algorithmic approach. APACTS can track this assessment proficiency at the question, learning objective, or skill level and provides remedial content at those levels as well. Instructional content can be provided to the learner in the form of static text, images, audio, or video. Assessments can be administered using multiple-choice questions (buttons and radio buttons), drag-and-drop annotation of images, drop-down menu selection, free input of text (with both exact matching and multiple correct responses), free input of text (manually scored), and numerical input with acceptable error ranges (see Figure 1). The instructor and/or content author can specify remediation paths which different learners may travel to best meet their learning objectives.

Within the APACTS system, content – assessments, instruction, remediation, tutorials, and surveys – are stored independently as "scenarios," permitting several scenarios to call the same content without storing redundant materials. As a learner logs in and completes these scenarios, a learner model is developed, and thus the learner is provided with content in accordance with recommendations from a Pedagogic Director and the authored scenario pathways. The specifics of the content path vary for individuals depending on their assessed comprehension of the material. To determine appropriate content, APACTS delivers assessments to learners and automatically grades these assessments using stored answer keys, including ranges of correct responses. Additionally, APACTS stores both learner assessments and progression through a scenario. This information can be accessed by the learner for review and reflection, and is also accessible to the instructor via a dashboard utility. By providing this data to the instructor or administrator, APACTS facilitates a feedback loop where administrator users can iteratively generate optimal and expansive scenarios.

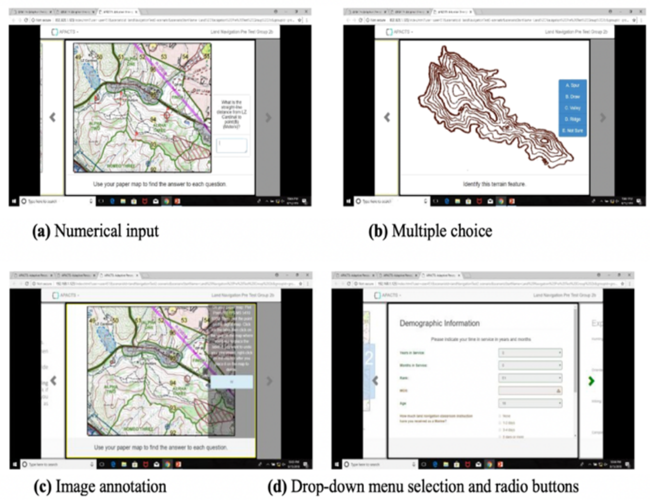

Figure 1. APACTs assessments: a) numerical input, b) single or multiple-answer multiple choice, c) image annotation, and d) drop-down menu and radio button selection

Adaptive Training Study

Using macro adaptations in the APACTS tool, the research team conducted an experiment to examine the effectiveness of an adaptive training approach in comparison to a traditional instructional approach. The researchers hypothesized that participants who received instruction tailored to their learning needs would demonstrate at least 25% learning gain as a result of that adaptive training intervention (H_1), and that the effect size associated with adaptive training in comparison to traditional instruction would be greater than .25 sigma as calculated with Cohen's *d* (H_2). These hypotheses, if supported, would suggest adaptive training technologies to be valuable to USMC formal schools as means of providing student-centered, information age instruction while gaining important efficiencies by optimizing both students' and instructors' time.

We selected classroom-based land navigation knowledge as the training content for the experiment. Because it is a training requirement for all Marines and, generally speaking, is standardized across USMC organizations, land navigation represents widely relevant content not subject to differences in application from one population to another. Land navigation is a core skill for the USMC, with map reading and wayfinding being cornerstone instruction for a variety of tasks, such as for Infantry Marines as they plan and execute their maneuvers, intelligence Marines who assess adversary capabilities given the physical characteristics of the battlefield, and combat engineers who build infrastructure such as radio towers and bridges. Once the basics of map reading are mastered, the higher-order infantry skills specific to SUDM may also be learned, such as the terrain reasoning skills underlying tactical decisions. Because of the criticality of land navigation, USMC instructors spend classroom time explaining the basic details of map reading, orienteering, and performing various wayfinding calculations which are then tested via practical application events where the students are required to use their knowledge to successfully navigate a given area. The use of an adaptive trainer for the task of land navigation is intended to increase the access and availability of instruction for Marines while freeing up instructor time to focus on the practical application rather than didactic knowledge recall.

METHOD

To measure the impact of adaptive training on learning in comparison to current instructional practice, we designed a pretest-posttest study using experimental and control groups. The experimental group received the adaptive training intervention in APACTS, while the control group received a non-adaptive intervention similar to current USMC classroom instruction, also via APACTS.

Participants

One hundred five Marine students at the USMC Intelligence School (MCIS), most of whom were attending the Intelligence Specialist Military Occupational Specialty (MOS) entry level course, participated in the experiment. Of the 105 students, 89 completed the testing and were included in the analysis. They ranked E1 to E4 and were young Marines ($M = 19.53$, $SD = 2.03$) with time in service of less than a year ($M = 0.70$, $SD = 0.83$). Seventy-eight students held an Intelligence MOS, three were Infantry MOSs, one was a Basic Utilities Marine, and seven did not specify an

MOS. All participants are assumed to have received classroom instruction and practical application exercises in land navigation prior to study participation, as shown in Table 1.

Materials

The data collection instruments, land navigation tests, instructional content, and adaptive training rules were embedded in APACTS. The specific content used for this experiment was as follows:

Tutorial. A brief Duck Hunt type game provided instruction on how to navigate APACTS and enter responses.

Pre-Session Questionnaire. The pre-session questionnaire consisted of 10 demographic questions and two self-efficacy questions. The demographic questions queried participants about their age, MOS, time in service, and experience outside the USMC with outdoor activities that might use land navigation skills, including hunting, camping, orienteering, geocaching, and hiking. Participants also reported the number of land navigation classroom instruction sessions attended and practical application exercises conducted. The self-efficacy questions required participants to rate, on a five-point scale, their agreement with the statements, "I feel confident in my understanding of land navigation course material," and "I feel confident that I will be able to apply land navigation skills in the field."

Table 1. Participants' Prior Land Navigation

Classroom Instruction Attended		Practical Application Completed	
# of Sessions	Participants	# of Exercises	Participants
None	0	None	0
1-2	23	1-2	33
3-4	36	3-4	42
> 5	28	> 5	11
no answer	2	no answer	3
TOTAL	89	TOTAL	89

Tests 1 and 2. Two land navigation tests derived from a School of Infantry–West land navigation test were created for use as pre- and post-tests. The tests consisted of 23 matched items addressing ten learning objectives, as depicted in Table 2.

Table 2. Land Navigation Test Learning Objectives

Learning Objective		# of Test Items
1	Plot a point with an accuracy of +/- 50 meters.	3
2	Measure straight-line ground distance between two points within a variance of +/- 100 meters.	2
3	Measure curved-line ground distance between two points within a variance of +/- 200 meters.	2
4	Measure the grid azimuth between two points within a variance of +/- 2 degrees.	2
5	Measure the magnetic azimuth between two points within a variance of +/- 2 degrees.	2
6	Measure the grid back-azimuth between two points with an accuracy of +/- 2 degrees.	3
7	Given a magnetic azimuth, measure the grid azimuth with an accuracy of +/- 2 degrees.	3
8	Measure the difference in elevation between two points with an accuracy of +/- 50 meters.	2
9	Given a magnetic azimuth, determine location of a point with an accuracy of +/- 50 meters.	2
10	Given a military topographic map, identify terrain features without error.	2
	TOTAL	**23**

Land Navigation Remediation. Remedial content, which consisted of instruction and three practice items, was created by the research team for each of the ten learning objectives. Members of the adaptive training group received the remedial content as their intervention, tailored to their individual performance as prescribed by the APACTS Pedagogic Director. Specifically, the APACTS Pedagogic Director was set to remediate a learning objective when the participant provided an inaccurate response to one of the pre-test items associated with that learning objective. This remediation consisted of text and videos that described the correct steps for successfully completing the land navigation task or problem in the learning objective. After viewing the remedial content, a practice item was given to the participant to test if they had mastered the topic. If the participant answered the practice item correctly, the participant was allowed to move on to the next topic. If the participant missed the practice item, they would be provided with up to two more practice items to continue to advance their skill and could also go back through the remedial content. The specific macro adaptation method of test – remediate – re-test was chosen so the utility of a simple and affordable solution could be empirically validated

Land Navigation Package. Participants in the non-adaptive group received 95 PowerPoint slides on land navigation from a USMC formal school as their remedial content between the pre and post-test. Participants could progress through these slides at their own pace.

Evaluation Survey. The evaluation survey consisted of seven questions. The first five questions elicited reactions to the APACTS tool regarding its ease of use, the value of the after-action review test feedback, and its appropriateness for land navigation training. The last two questions were self-efficacy items identical to those used on the pre-session questionnaire to measure self-reported confidence in land navigation after completing APACTS.

APACTS Adaptive Training System: The APACTS system was populated with the pre-session questionnaire, land navigation instructional content, Test 1 and 2 assessments, and the evaluation survey. For this research, all student response data were collected within APACTS and available for viewing in the instructor dashboard and exporting to Excel. In addition, the Pedagogic Director was programmed to provide an after-action review to students following both tests. Learning objectives were coded green when all corresponding questions were answered correctly, or red when one or more question on the learning objective was answered incorrectly. In the after-action review, students could review their own answer and the correct answer for every item.

Because the content chosen was land navigation, the assessment methods used in this study included four assessment formats. In some items, students were asked to place a designated point on a map (image annotation; see Figure 2). Four multiple-choice single-answer questions required the student to identify a specific terrain feature (ridge, saddle, etc.). The majority of the questions were numerical-input questions requiring the student to calculate specific azimuths, distances, and grid locations. Each of the numerical-response questions allowed the student to answer within a range commensurate to the margin of error acceptable for USMC instructors (for example, an answer could be within ± 2° of the given correct answer). APACTS automatically graded each of the assessed items in order to produce an overall score and a score per learning objective (see Table 2).

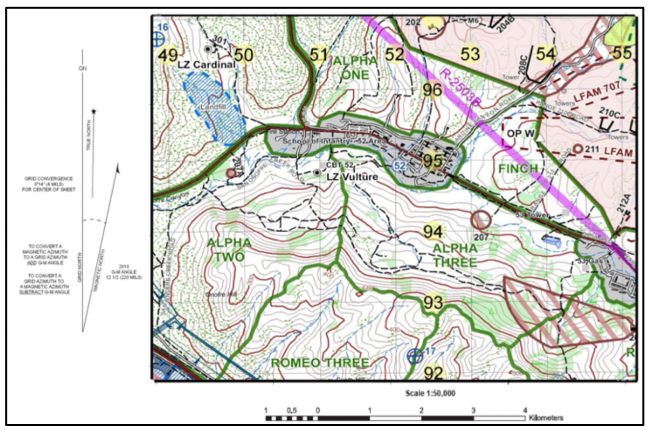

Figure 2. Topological Map Used for Land Navigation

In addition to the materials described above and embedded in APACTS, an informed consent form was prepared to describe the purpose of the study and explain participants' rights, and a laminated map, protractor, and map pens were provided to students allowing them to use physical maps as they normally would to find answers to the test items.

Procedure

Test sessions were conducted in a simulation laboratory at MCIS with 20 test stations. A total of six two-hour sessions were conducted over two consecutive days. Researchers prepared the room in advance of each session by placing either a green or orange index card with login credentials at every other station. Participants were randomly assigned to the control or experimental group based on whether they selected a station with a green or orange index card. Students were not informed of the difference between colored cards, only that they denoted different versions of the test. Upon session start, one research proctor verbally summarized the purpose of the study, reviewed the informed consent form, and requested signatures on the consent forms. A second proctor then provided instructions, including the sequence of activities to follow in APACTS, a reminder that each station would present a different version of the content, and direction to use the laminated maps to calculate answers. The proctors and an APACTS programmer were available throughout the session to fix problems or answer questions unrelated to the land navigation content.

Following receipt of verbal instructions, participants completed four "scenarios" in APACTS independently, in sequence, and at their own pace. The first scenario consisted of the APACTS tutorial. In the second scenario, participants completed the pre-session questionnaire and the Test 1 pre-test. The third scenario for the experimental group consisted of the adaptive training. The learning objectives for which remediation was provided depended on participant performance on that learning objective during the pre-test. Similarly, the number of practice items provided during remediation depended on whether participants correctly answered the previous practice item. Thus, students who missed several pre-test items received more remedial instruction, while those who only struggled with one or two learning objectives received additional instruction for those topics alone. Participants were permitted to proceed through the remediation at their desired pace, and they were allowed to go backward to re-review content or forward to skip content. APACTS recorded time spent in remediation. For control group members, the third scenario consisted of the land navigation package. Like the experimental group, control group members were permitted to move quickly or slowly, and navigate backward or forward, through the slides. The control group did not receive tailored instruction and did not receive practice items. As with the remediation group, APACTS recorded time spent in the land navigation package by control group members. The fourth and final APACTS scenario consisted of the Test 2 post-test and was administered to participants in both groups. At the end of the post-test, participants completed the evaluation survey and were excused.

ANALYSIS

Test 1 and Test 2 Equivalency

During pilot testing, Tests 1 and 2 were examined to assess the feasibility of treating the tests as equivalent in difficulty. Marines attending an entry-level Intelligence MOS course at Fort Belvoir, Virginia, completed the APACTS sessions, with roughly half the population ($n = 24$) receiving Test 1 at pre-test and the other participants ($n = 18$) receiving Test 2 as the pre-test. Scores at pre-test on Test 1 ($M = 59.41\%$, $SD = 19.59\%$) were not significantly different than scores on Test 2 ($M = 62.74\%$, $SD = 23.63\%$), $t(40) = .50$, $p = .62$. The tests were therefore treated as similar in difficulty for the study, with Test 1 employed as the pre-test for all participants and Test 2 used as the post-test.

Learning Gains

The primary objective of this analysis was to examine the learning gains achieved by study participants. Learning gain was defined as actual improvement from pre-test to post-test relative to room for improvement, and used the formula (post-test score minus pre-test score) divided by (total questions minus pre-test score). For example, if an individual scored 17 out of 23 on the pre-test and improved to 20 out of 23 on the post-test, she would have achieved 50% learning gain. Six additional points represented her room to improve from pre- to post-test, and she scored three, or 50%, of those additional points.

The first hypothesis (H_1) stated experimental group participants would demonstrate at least 25% learning gain from pre-test to post-test as a result of the adaptive training intervention. To assess H_1, test scores were obtained and learning gains calculated for the experimental group ($n = 44$). Participants in the experimental group showed score improvement from pre-test ($M = 50.49\%$, $SD = 24.31\%$) to post-test ($M = 71.74\%$, $SD = 21.90\%$). This improvement represented a mean learning gain of 42.36% ($SD = 32.58\%$), demonstrating a larger average learning gain than the hypothesized 25%.

The second hypothesis (H_2) stated that participant performance from pre-test to post-test would improve for both groups, with the experimental group showing an effect size, calculated with Cohen's *d*, of at least .25 sigma over the control group. Test scores were obtained and learning gains calculated for the control group ($n = 45$). Like the experimental group, control participants also improved from pre-test ($M = 51.98\%$, $SD = 18.88\%$) to post-test ($M = 61.26\%$, $SD = 20.39\%$). These improvements represent a mean learning gain of 16.37% ($SD = 38.49\%$). A paired sample t-test conducted on participant learning gains confirmed the experimental group gain to be significantly greater than the control group gain, $t(87) = 3.43$, $p < .001$. The effect size for this analysis ($d = .69$) exceeded the expected effect size of .25. Figure 3 illustrates that the learning achieved by experimental participants who received training and extra practice tailored to their performance needs was greater than that of control participants who received the existing instructional slides.

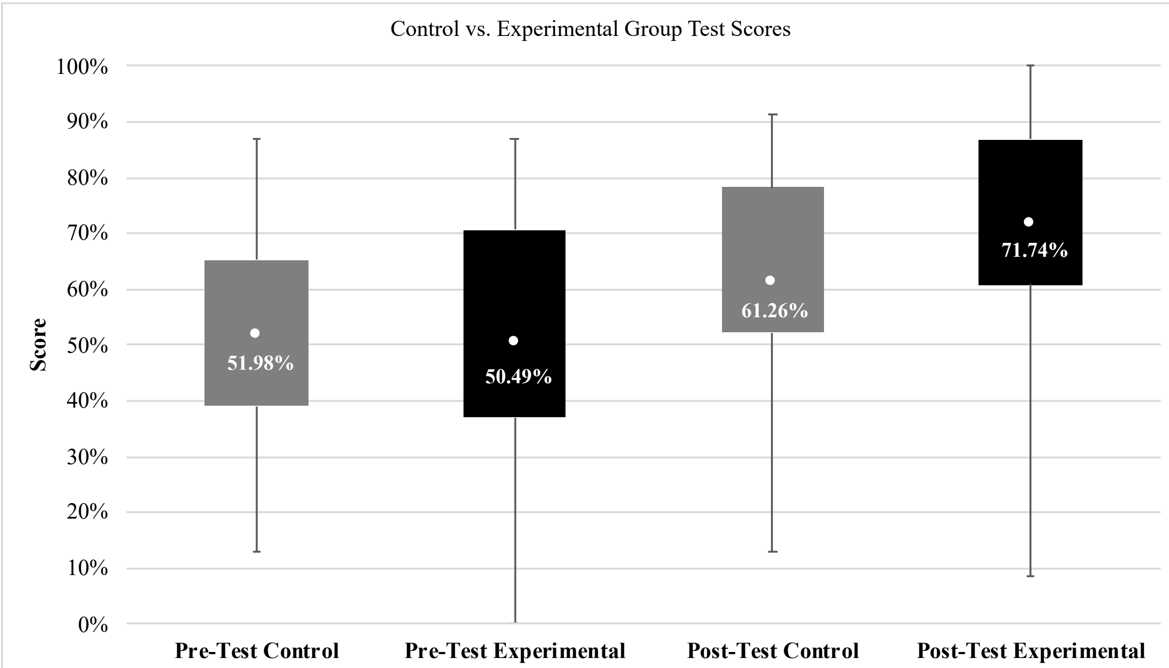

Figure 3. Experimental group participants achieved greater learning gain than control participants.

Additional analyses were conducted to determine whether the adaptive training condition had a more pronounced impact on the learning gain of individuals with differing levels of incoming land navigation knowledge. Learning gain was assessed for individuals whose pre-test scores fell at or below the median score of 52.17% compared to those with pre-test scores above the median. Like the analysis of the entire population, the learning gain of experimental group participants scoring under the pre-test median ($n = 22$, $M = 45.56\%$, $SD = 28.75\%$) was larger than the gain experienced by control group members under the pre-test median ($n = 26$, $M = 18.31\%$, $SD = 26.79\%$), $t(46) = 3.39$, $p < .001$, and the effect size ($d = .89$) of this difference was larger than for the population as a whole.

The associations among demographic factors and learning gain were analyzed to determine whether past experience in land navigation or similar activities contributed to the learning achieved. Correlations were calculated between nine demographic factors and learning gain, shown in Table 3. Only one factor, time in service, showed a slight relation to learning gain, $r(86) = -.316$, $p = .003$, indicating larger learning gains for individuals with fewer months in the USMC. Upon closer investigation, the inverse relationship between time in service and learning gain was shown to be stronger for individuals in the experimental group, $r(41) = -.445$, $p = .003$, and not significant for those in the control group, $r(43) = -.267$, $p = .076$. While one might expect the relationship between time in service and learning gain to be a product of the amount of land navigation instruction received, neither classroom instruction nor practical application experience correlated with learning gain (see Table 3).

Table 3. Pearson's *r* Correlations between Learning Gain and Demographic Factors

	Time in Service (months)	Age	Classroom Instruction	Practical Appli-cations	Hunting Experience	Camping Experience	Orienteer-ing Experience	Geocach-ing Experience	Hiking Experience
Learning Gain	-.316**	-.058	-.108	-.190	-.159	-.126	-.129	-.028	-.070

**$p < .01$; $n = 88$ for all cells

Self-Efficacy

Student reports of confidence in their land navigation skills were examined to determine whether the experimental group participants would report greater improvements in self-efficacy than control group participants from pre-test to post-test, and whether self-efficacy would show greater improvements for classroom land navigation skills (i.e., understanding) than field land navigation skills (i.e., application). Participant ratings of self-efficacy taken from the Pre-Session Questionnaire and Evaluation Survey on "*understanding* of land navigation course material" and "*application* of land navigation skills in the field" were assessed for changes from the start of the APACTS session, prior to the pre-test, to the end of the session, after post-test. Prior to pre-test, the experimental group ratings of confidence in *understanding* (M = 3.70, SD = 0.94) did not differ from the control group (M = 3.49, SD = 1.01), $t(86)$ = 1.02, p = .31. However, after the intervention and post-test, the experimental group (M = 3.81, SD = 0.82) was more confident than the control group (M = 3.33, SD = 0.98), $t(86)$ = 2.52, $p < .02$. Similar outcomes resulted on ratings of *application* confidence, with the experimental group (M = 3.88, SD = 0.85) and control group (M = 3.73, SD = 0.86) reporting similar confidence prior to pre-test, $t(86)$ = 0.82, p = .41), but experimental group participants exhibiting higher confidence (M = 3.98, SD = 0.74) than the control group (M = 3.42, SD = 1.03) after the post-test, $t(86)$ = 2.95, $p < .01$. These findings are depicted in Figures 4 and 5. Interestingly, both groups showed higher mean scores in their ratings of *application* than *understanding* confidence, although this difference was not statistically significant. This trend is the opposite of what the researchers expected.

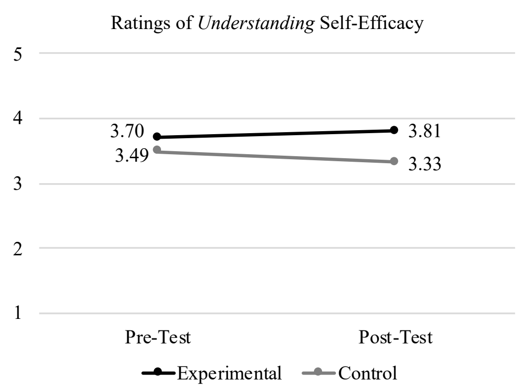

Figure 4. After the intervention, experimental participants reported higher understanding self-efficacy than control participants.

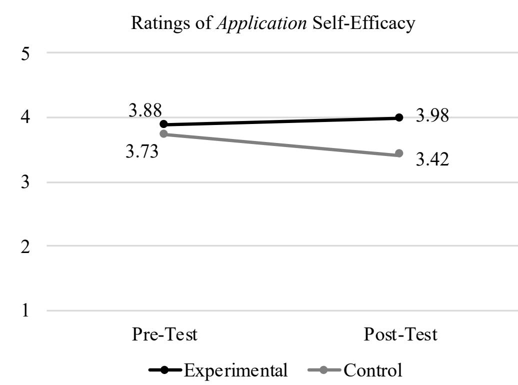

Figure 5. After the intervention, experimental participants reported higher application self-efficacy than control participants.

Upon closer inspection, it appears the post-session differences in self-efficacy may be attributable to both an increase in experimental group confidence and a decline in control group confidence. Although none of these within-group differences were statistically significant, the experimental group's mean ratings of confidence on both *understanding* and *application* trended upward and decreased in variability from pre-test to post-test (*understanding* pre-test M = 3.70, SD = 0.88; *understanding* post-test M = 3.81, SD = 0.67; *application* pre-test M = 3.88, SD = 0.72; *application* post-test M = 3.98, SD = 0.55). Among control group participants, mean ratings of *understanding* confidence trended downward from pre-test (M = 3.49, SD = 1.03) to post-test (M = 3.33, SD = 0.95). The *application* confidence of the control group was nearly significantly lower after the post-test (M = 3.42, SD = 1.07) than before the pre-test (M = 3.73, SD = 0.75), $t(44)$ = 1.96, p = .056.

DISCUSSION

The outcomes of this study provide additional support for the assertion that ATS providing tailored instruction to individual needs can be highly effective learning tools, and more effective than traditional teacher-centric instructional approaches or non-adaptive training interventions. Interactive facilitation approaches that enable students to take control of their learning and receive feedback and targeted instruction have been found to produce higher levels of engagement, learning, and retention (Sheridan & Kelly, 2010; Wlodkowski & Ginsberg, 2017; Zull, 2002). The adaptive training system also resulted in increased student self-efficacy in their understanding of the material and perceived ability to transfer their learning into practice. Higher levels of student efficacy in training are essential predictors for learning transfer on the job (Broad & Newstrom, 1992; Merriam & Leahy, 2005; Stevens & Gist, 1997; Warr, Allan, & Birdi, 1999). Therefore, adaptive training technologies may be instrumental for the USMC in achieving current directives to bring training into the information age, promote a self-directed instructional model, and focus the limited but valuable resource of instructor time and attention to where it is needed most.

The macro adaptive training approach undertaken in this study demonstrates that a simple and affordable adaptive solution can still yield significant learning gains over current approaches. While micro adaptations, which dynamically branch instructional content on the basis of student responses, have been shown to be highly effective (e.g., Dzikovska, Steinhauser, Farrow, Moore & Campbell, 2014; Landsberg, Astwood, Van Buskirk, Townsend, & Steinhauser, 2012), these solutions are expensive to build, dependent on programmer expertise, and highly customized to a particular training task. The macro adaptations instantiated in APACTS are produced in a content-agnostic manner whereby tailoring occurs based on the number of incorrect answers on individual learning objectives. This design is simple enough that instructors or curriculum developers can create their own content and adaptive rules without assistance from software developers. To that end, an APACTS content editor is in development and currently being piloted by two USMC formal schools.

Participants receiving the adaptive training condition experienced significant learning gains in under two hours of classroom time. The learning return on students' investment of time suggests the implementation of adaptive training in formal schools could produce increased levels of learning without increasing course duration. The effect of the adaptive training approach was more pronounced for individuals with lower levels of incoming knowledge, suggesting the application may be highly advantageous for students with little exposure to the learning material or requiring remediation. Furthermore, no Marine instructors were involved in the administration of instruction nor scoring of assessment items during this study. If implemented, adaptive training solutions could result in a substantial decrease in the time required of instructors to remediate students on those learning objectives, and this approach is amenable to student self-directed instruction.

An unexpected benefit of the APACTS ATS was its ability to visually represent student responses in the dashboard. Instructors viewing the range of student responses for each question were able to quickly recognize common errors and misconceptions. For example, on the questions requiring plotting points, the dashboard provided "heat maps" showing where students plotted their answers in relation to the correct answer. When many students produced the same incorrect plot, instructors were able to identify the miscalculation responsible for the errors. The value of these insights for instructors lies in their ability to adapt their classroom instruction or individual remediation to address the misconceptions.

Of importance is the research question of what knowledge types and learning objectives are most appropriate for self-directed adaptive training, and which are best instructed by a human. In this study, the land navigation learning objectives reflected primarily declarative and procedural knowledge, as well as elements of conceptual knowledge. The authors contend that these three knowledge types are well suited for self-directed adaptive training, with mechanical skills and higher order decision making, problem solving, and other cognitive skills requiring a human instructor. These remain empirical questions. However, the buy-back in instructor time as a result of introducing adaptive training would allow them to focus their efforts on instructing those higher order knowledge and skill types.

Another research question to be investigated involves the transfer of training issue, to assess whether the knowledge gained in an adaptive training setting can be applied in practical situations to the same degree as knowledge learned in an instructor-led classroom. For our study specifically, it would be ideal to research the impact of the training on land navigation practical examinations in the field.

Based on the findings presented, three potential use cases would likely benefit from the inclusion of an adaptive system such as APACTS and macro adaptive remediation. The first use case is to make adaptive training available to students who are struggling with specific concepts. A student who self-identifies as needing additional help can use an adaptive trainer to be assessed on individual learning objectives and obtain remediation on only the items needed. The second use case would be to remediate students who fail practical applications and other performance events, as identified by instructors. Using the APACTS system would allow the student self-remediate to catch up with the rest of the class. The third and revolutionary use case is that of adopting a flipped classroom model where direct instruction takes place in a self-paced manner with the support of an ATS, while classroom time is spent in highly interactive discussions and exercises where the online instruction is applied to problem sets. The notion of the flipped classroom is one that is being adopted nationwide in more academic settings, and has been suggested as a desired and necessary paradigm for Marine leaders. All of these use cases provide the benefit of an increase in knowledge acquisition by the Marine students and allow instructors to capitalize on their expertise with more engagement instructing complex, critical, and decision-centered tasks.

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